Monitoring Beaked Whale Movements During Submarine Commanders Course Using Satellite Telemetry Tags

Diane Elaine Claridge
Bahamas Marine Mammal Research Organisation
P.O. Box AB-20714
Marsh Harbour
Abaco, Bahamas
phone: (242) 366-4155 fax: (242) 366-4155 email: dclaridge@bahamaswhales.org

Dr. John William Durban
NOAA Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, CA 92037
phone: (858) 334-2866 email: John.Durban@noaa.gov

Award Number: N000141010240
http://www.bahamaswhales.org

LONG-TERM GOALS

This project is focused on the potentially harmful effects of mid-frequency active sonars used by the US Navy on beaked whales and other deep-diving odontocetes. In response to this concern, satellite telemetry is being used to monitor the movements and diving behavior of beaked whales and other odontocete cetacean species on the US Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) range before, during and after sonar exercises; and to study the movement patterns and diving behavior of odontocetes more widely in the canyons of the northern Bahamas to obtain baseline data.

OBJECTIVES

The primary goal of the project is to measure the potential effects of a military operation involving multiple ships using mid-frequency active sonar on the movements of beaked whales and other odontocetes. Specifically, the objectives are:

- To deploy satellite telemetry tags before the November 2009 SCC to track the movements of beaked whales before, during and after the SCC and compare movement patterns with and without the presence of MFA tactical sonars.
- To photo-identify individuals within each beaked whale group to match to an existing catalogue and assess their age and sex classes to determine if movement differs by individual and/or age/sex and to aid in resighting of tagged animals post-tagging (as a future separate effort).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2010		**00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Monitoring Beaked Whale Movements During Submarine Commanders Course Using Satellite Telemetry Tags	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NOAA Southwest Fisheries Science Center,8604 La Jolla Shores Drive,La Jolla,CA,92037**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**8**	

- To obtain biopsy samples from beaked whales using remote sampling techniques to contribute towards a study of their population structuring, to examine possible genetic covariates for movement patterns, and to measure cortisol levels in the blubber as an indicator of baseline stress levels of beaked whales at AUTEC (part of a separate project).

Secondary objectives are:

- To deploy satellite tags, collect biopsy samples and photo-identify non-beaked whale species, including sperm whales, pilot whales, false killer whales and melon-headed whales. This work will occur only when working with beaked whales is deemed impossible, due to inclement weather or lack of accessibility to animals.

APPROACH

This project represents a collaboration between the Bahamas Marine Mammal Research Organisation (BMMRO), the Protected Resources Division of the NOAA Southwest Fisheries Science Center (SWFSC), and the US Naval Undersea Warfare Center (NUWC), with field logistics funded by the Office of Naval Research and tagging funds provided by the NOAA Ocean Acoustics Program. The work was conducted under Bahamian research permit (permit no. 1) issued to the Bahamas Marine Mammal Research Organisation under authorization of the Bahamas Marine Mammal Protection Act 2005.

Transmissions from Low Impact Minimally Percutaneous External Transmitter (LIMPET) tags were used to calculate animal locations and infer diving behavior; continuous-time correlated random walk models were fit to these data to estimate detailed movement tracks and variations in displacement speed; and the animals' received sonar levels will later be calculated using standard Navy propagation models and by incorporating animal and ship movements into the Navy's NUWC/ESME effects model.

The project was conducted within the AUTEC-Andros Operating Area in the northern Bahamas (Figure 1). An acoustic team from NUWC were on site to operate the Marine Mammal Monitoring on Navy Undersea Ranges tool (M3R). A 6.8 m Novurania rigid-hulled inflatable boat (RHIB) was vectored to animals on the AUTEC range using animal location information transferred to the RHIB by M3R. The tagging team consisted of four personnel: chief scientist and captain, Diane Claridge (BMMRO); photo-id/data recorder, Charlotte Dunn (BMMRO); biopsy/photo-id, Robert Pitman (SWFSC); and tagger (including analysis), John Durban (SWFSC). When a group of animals was sighted individuals within the group were photo-identified, and biopsy and tagging attempts were made on sub-adult and adult animals (but not on calves), with the first priority being to deploy satellite tags.

The movement of individual whales was monitored by deploying satellite LIMPET tags (e.g. Andrews et al. 2008), with a location-only satellite transmitter (SPOT5 model, Wildlife Computers, Redmond, WA). This small tag was held on the external surface of the whale, ideally near the base of the dorsal fin/hump, by two barbed titanium darts which threaded into the tag and penetrated to a depth of 4.5 cm or 6.5 cm, depending on the targeted species (Figure 2). Tags were deployed from distances of approximately 8 - 25 m using a black-powder rifle to project the tag on the end of a crossbow bolt, which fell away on contact with the whale.

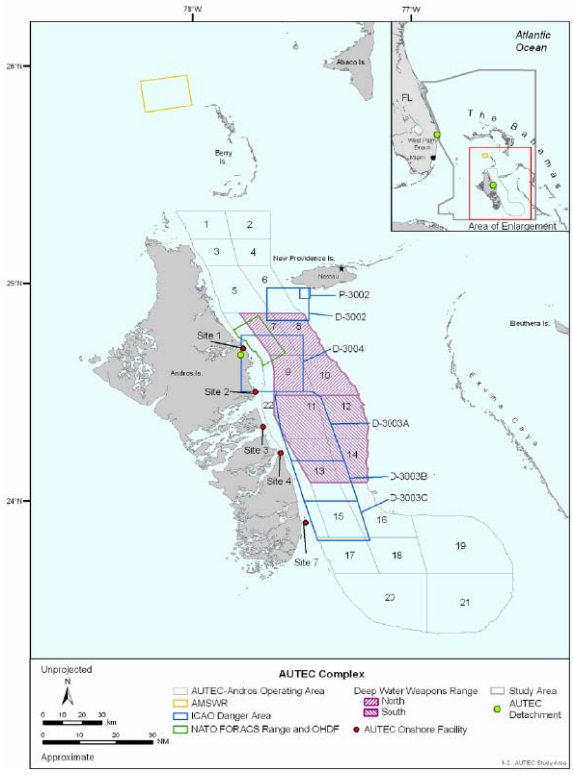

Figure 1. The AUTEC Range Complex located east of Andros Island in the central Bahamas. The field work took place in the central part of the range, in Operating Areas 7-14 (shown in purple).

Figure 2. Satellite dart tag attached near the base of the dorsal fin of an adult male short-finned pilot whale (Globicephala macrorhynchus).

The tags were scheduled to transmit for six 2-hour periods each calendar day, and transmissions from the tag were recorded and processed using the ARGOS system (http://www.argos-system.org/). The tags were also programmed to record time-at-temperature data, as a proxy for dive depths. The tags

were programmed to log and transmit the proportion of 10-second recording intervals in which the tag's internal temperature sensor recorded temperature in 12 temperature bins (<4ºC; >24ºC; and 10 bins of 2ºC increments between 4ºC and 24ºC). Because of the large temperature gradient between the surface and deep water in the Bahamas, this gives a very usable proxy for diving behavior. Separate temperature histograms were produced for each 6-hour interval (01:00-06:59, 07:00-12:59, 13:00-18:59, 19:00-00:59) during the life of the tag, providing the potential to examine for diurnal differences in dive depths and providing resolution for detecting spatially-linked changes in diving behavior over time.

To assess animal movements, swim speed and habitat use, inference from tag data was made based on continuous-time correlated random walk models (Johnson *et al.* 2008). Using this approach, errors in the Argos location calculations were accounted for and the animal's location (and uncertainty about its location) was predicted at any given point in time, allowing detailed tracks and links to continuous habitat covariates. Displacement velocities were estimated throughout the track, allowing changes in displacement speed to be identified and related to movements, diving and habitat. Velocities and dive profiles, where available, were linked to identify behavioral shifts (e.g. to detect prolonged feeding bouts or extended travel).

WORK COMPLETED

The tagging field effort was based from AUTEC from October 24th to November 7th 2009, with field work conducted on nine days in the RHIB. Due to inclement weather conditions, only one beaked whale group was found, consisting of two adult Cuvier's beaked whales (*Ziphius cavirostris*), but this group was not approachable for tagging. However, there were eight sightings of non-beaked whale species. This included two sightings of short-finned pilot whales (*Globicephala macrorhynchus*) during which six satellite dart-tags were successfully deployed on six adult or subadult whales, with three deployments on October 26th and three on November 5th. Transmissions were received from all of the tags, which transmitted for up to 27 days, and locations were calculated from receptions by the ARGOS satellite system.

The locations calculated from tag signals provided valuable baseline information on the scale of movements for this species in this area (Figure 3), including movement data in the area of the AUTEC range before, during and after the SCC.

This project provided a valuable opportunity to test the performance of the 4.5 cm dart-tags because the same group was resighted 10-days after deployment (Table 1). Relocation of the group was possible by remote tracking of the tag transmissions and fine-scale searching in response to positions obtained from acoustic localizations relayed from M3R. The attachment of one of the tags was not optimal, as last-minute movement by the animal led to an off-angle hit and only the posterior dart penetrated fully into the fin. So, it was no surprise that this only transmitted for 8 days before detaching. When this animal was resighted, it was confirmed that the tag had indeed detached. A second tag was deployed (on a different animal) on the dorsal ridge just at the posterior base of the dorsal fin. This tag only transmitted for 10 days, possibly because the looser tissue structure at the attachment site than on the dorsal fin itself.

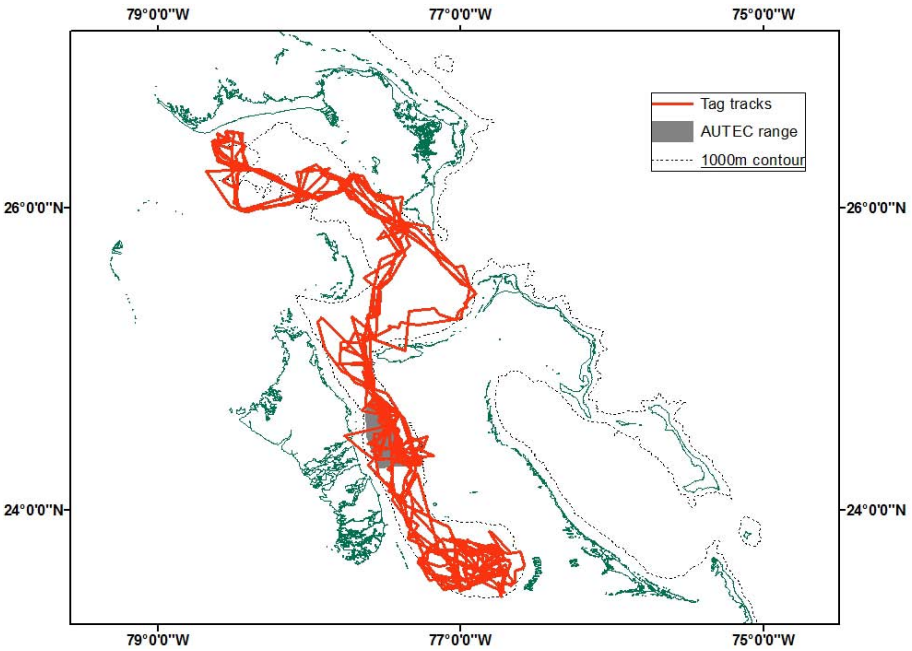

Figure 3. Tracks from six pilot whales tagged at AUTEC during October-November 2009. The group ranged throughout the Great Bahama Canyon during the 37 days of transmission, spending the majority of time in the Cul de Sac at the south end of Tongue of the Ocean.

Table 1. Summary data on the performance of six satellite dart-tags that were deployed on the AUTEC range in October and November 2009.

Tag PTT number	Attachment Date	Last transmission	Duration (days)	# Locations
93215	05-Nov-09	01-Dec-09	27	276
93218	26-Oct-09	02-Nov-09	8	63
93220	26-Oct-09	14-Nov-09	20	240
93231	26-Oct-09	16-Nov-09	22	195
93233	05-Nov-09	16-Nov-09	12	86
93241	05-Nov-09	14-Nov-09	10	69

The median deployment duration of the four tags that appeared optimally deployed on the dorsal fin was 21 days. Two pairs of tags stopped transmitting on the same day, despite one of each pair being deployed ten days apart suggesting that the whales may have removed them from each other, perhaps in a social gathering as has been observed with social groups of resident killer whales (JWD, *pers. obs.*). The pilot whales were all were travelling together at this time. The longest transmission period was 27 days which allowed the group's movement to be tracked during the SCC mini-war. This project successfully collected movement data before, during and after the SCC, as with the Blainville's beaked whale tagged at AUTEC in May 2009 with 4.5 cm dart length.

RESULTS

There were 929 locations in total received over 37 different days (median per tag = 16 days, range = 8-27 days), successfully collecting movement data for the pilot whales before, during and after the SCC, and most importantly during the mini-war (14 – 17 November) when multiple MFAs were active.

In contrast to the movements recorded for a Blainville's beaked whale (*Mesoplodon densirostris*) tagged at AUTEC in May 2009, instead of moving away from sound sources, the tagged pilot whale showed no evidence of a response.

This whale, an adult male, traveled south towards and through the AUTEC range during the SCC, at a time when active sonar operations were underway (Figure 4). Specifically, on November 16th, the whale approached during active operations and tracked south across the range during a multi-ship sonar operation that began at 09:00 local time, finished at approximately 16:00L then resumed again at 18:00L. M3R detected pilot whale clicks in the afternoon on the 16th in the south of the range providing evidence that the group of whales was transiting the range and not just the whale with the remaining tag. During this time there were multiple sonars, pingers, UQCs, and countermeasures that were active (D. Moretti, *pers. comm.*). The activities ended at 21:52L on the 16th, but notably, there was a gap from 14:39-1810L with no activity. This gap period includes some of the time the whales were on the south part of the range.

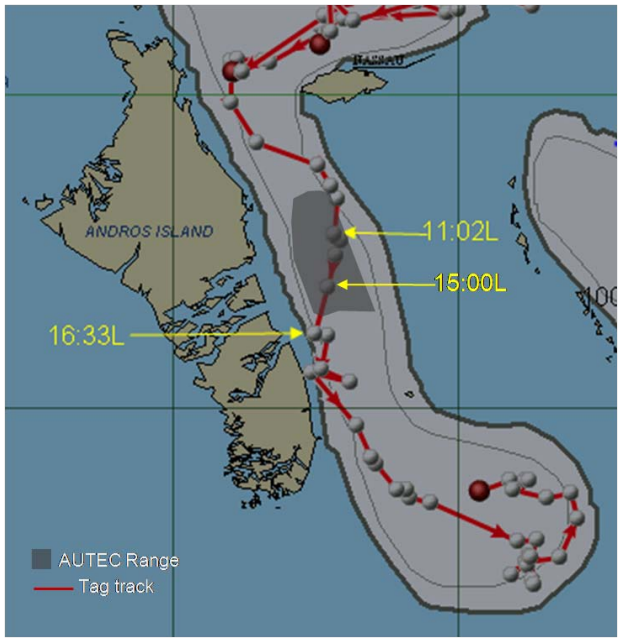

Figure 4. Pilot whale track showing its movement south through the range during the SCC mini-war on 16 November 2009. The times shown are times for which tag locations were received.

As the whale passed southward through the range during the SCC, it showed no observable change in swim speed or diving behavior. The continuous-time correlated random walk models fit to the location data showed no obvious variation in the whale's movement and in displacement speed during the SCC (Figure 5).

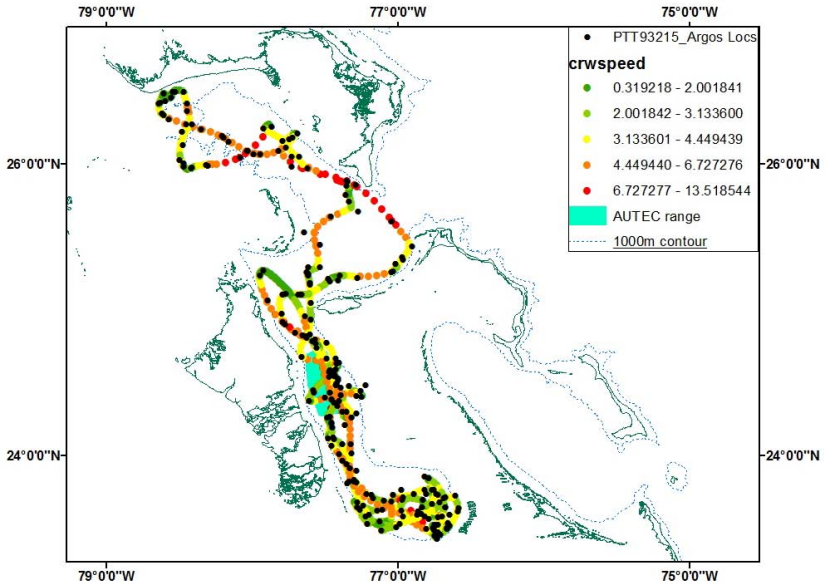

Figure 5. Modeling satellite tag location data to assess movements and displacement speeds before, during and after the SCC. No obvious change in swim speed was noted as the whale swam through the AUTEC range during the sonar test.

Furthermore, temperature/dive data analyzed to test for any diving responses associated with movement through the AUTEC range during the SCC showed no change in diving behavior. The tag was set to produce a separate time-at-temperature histogram for each of four 6-hour time periods in each day. The whale's passage southbound through the AUTEC range during the SCC on November 16th encompassed two of these periods (0700-1259 local time and 1300-1859 local time). These "morning" and "afternoon" periods were compared with the average time at temperature histograms for the corresponding 23 and 25 other morning and afternoon periods, respectively, that were logged during the life of the tag (Figure 6). However, the whale did not stay on the AUTEC range for the entire (or majority) of the tag duration, so the SCC histograms were also compared to additional morning (n=2) and afternoon (n=2) periods when the whale was on the range, outside of the time when the SCC was underway.

Two aspects of the dive behavior are interesting. Firstly, this whale spent more time at the surface in the afternoon, on average, than in the morning. This was consistent with data from the other five tags that were deployed on pilot whales in November. Secondly, this whale's dive profiles were very consistent across days, within each recording period. There was no signal of a change in diving behavior during the SCC, when compared to either the overall average for each recording period or the average of the recording periods when the whale was actually on the AUTEC range.

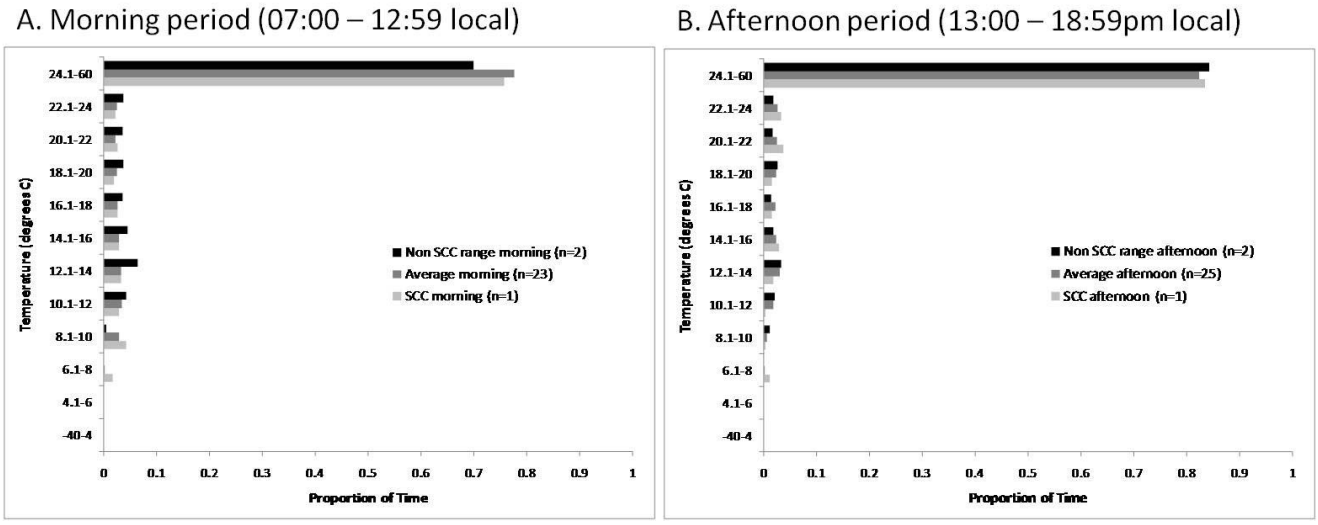

Figure 6. Dive histograms for pilot whales during two time periods: morning (A) and afternoon (B).

A key part of interpreting these findings is linking movements and behaviors to received sound levels. Propagation modeling is being done by D. Moretti and his team at NUWC to estimate received levels which are predicted to be significant. Additionally, behavioral responses of individuals need to be related to physiological and population effects.

IMPACTS/APPLICATIONS

The Navy is increasingly recognizing the need to minimize harm to cetaceans wherever possible during operations. It is clear that to minimize the potential impacts of sonar systems on beaked whales and other species, an understanding of the mechanisms underlying atypical mass strandings is developed. Controlled sound exposure experiments are providing the basis for this understanding by identifying a behavioral response that can be used as a safe indicator for risk of stranding, and defining the exposures required to elicit beaked whales with a full dose: response analysis. Monitoring the movements of whales in response to a real sonar exercise will allow these findings to be applied at the population level. Together, these studies will provide the Navy with a basis for developing mitigation measures during sonar exercises. This current work emphasizes that caution must be used in interpreting data from small sample sizes, and highlights the need to obtain further data from a variety of species during sonar exercises in order to identify and describe species-specific behavioral responses and vulnerabilities.

REFERENCES

Andrews, R. D., R. L. Pitman, and L. T. Ballance. (2008). Satellite tracking reveals distinct movement patterns for Type B and Type C killer whales in the southern Ross Sea, Antarctica. *Polar Biology* 31: 1461-1468.

Johnson, D. S., J. M. London, M. Lea, and J. W. Durban. (2008). Continuous-time correlated random walk model for animal telemetry data. *Ecology* 89:1208–1215.